

AIRBREATHING COMBINED CYCLE ENGINE SYSTEMS

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The Air Force Wright Research and Development Center's Aero Propulsion and Power Laboratory (WRDC/PO) and the National Aeronautics and Space Administration's Lewis Research Center (NASA LeRC) share a common interest in developing advanced propulsion systems for commercial and military aerospace vehicles which require efficient acceleration and cruise operation in the Mach 4-6 flight regime. The principal engine of interest is the turboramjet; however, other combined cycles such as the turbosramjet, air turborocket, super-charged ejector ramjet, ejector ramjet, and air liquefaction based propulsion are also of interest. Over the past months careful planning and program implementation have resulted in a number of development efforts that will lead to a broad technology base for these combined cycle propulsion systems. Individual development programs are underway in thermal management, controls materials, endothermic hydrocarbon fuels, air intake systems, nozzle exhaust systems, gas turbines and ramjet ramburners.

In 1986, NASA LeRC and WRDC/PO initiated studies with Rolls-Royce, General Electric, and Pratt and Whitney to evaluate and configure advanced combined cycle propulsion systems/fuels for future mission applications. Two missions were selected; a long duration cruise vehicle (Mach 4-6) and a horizontal takeoff two stage-to-orbit vehicle. The three studies were consistent in selecting turbomachinery based combined cycle engines as the preferred cycle. A number of critical component technologies were identified during the studies which must be investigated before a turbomachinery based combined cycle engine can be demonstrated. A few of the more critical component technologies are discussed.

THERMAL MANAGEMENT

The maximum speed for high Mach aircraft will be established by the thermal management system. Design practice has been to employ fuel/air heat exchangers to provide cooling air for many of the engine components while the airframe was cooled by passive means. Flight in the Mach 4-6 regime can result in leading edge temperature as high as 1800°F from aerodynamic heating. The engines will operate with compressor exit and turbine entrance temperatures that approach the limits of standard structural materials. The thermal loads from the airframe, avionics, crew environment, and engines will increase greatly above the levels normally handled by the incoming air and standard hydrocarbon fuels. Therefore, thermal management systems for the high Mach applications must resort to the heat sink capability of advanced fuels since even the stagnation air temperature will exceed the materials structural limit in many cases.

Endothermic hydrocarbon fuels show promise of handling the higher heat loads of the high Mach aircraft up to flight speeds exceeding Mach 6.0. Fuel temperatures of 1400°F and pressures to 500 psi are indicated after passage through the thermal management system loop. Advances in every component of the fuel management system will be required including pumps, regulators, tubing, connectors, heat exchangers, catalytic reactors, etc. System architecture

studies will be required to ensure proper arrangement of components for minimum weight systems.

AIR INTAKE SYSTEMS

The air intake system for the high Mach aircraft poses a number of unique design requirements not found in lower speed applications. Matching the air capture schedule versus engine airflow demand over a broad speed range requires compromise at the operating extremes. Excess spillage drag at low speed requires higher thrust since spillage drag can be as much as 25% of the total vehicle drag at transonic conditions. Boundary layer limit will be required to limit the amount of low energy air entering the propulsion system. Control can be achieved through boundary layer bleed or regulating the temperature ratio between the freestream air and the inlet surface. Temperature control of the inlet surface may unduly complicate the thermal management system. It has been shown that 1% bleed flow can cause up to 5% reduction in net thrust. The inlet designer must account for the air flow that is required to cool the engine hot section, lubrication system, and exit nozzle. Cooling air flow up to 15% of that captured may be required. Inlet physical size may in fact be the largest design problem. Preliminary designs of air intakes show that the configurations will be as much as three times larger and weigh four times heavier than those for Mach 1.5 aircraft. Innovative thinking will be required to keep the inlets short and light.

EXIT NOZZLE

The engine exit nozzle will be required to operate efficiently over a wide speed range. Optimal contouring of the expansion surface will be necessary since even a 1% change in gross-thrust coefficient can result in an 8% reduction in net thrust. Variable geometry components will be required to accommodate the large expansion ratios, up to 40:1 at Mach 6, to expand the exhaust flow to ambient pressure. Variable geometry by its very nature poses a sealing problem and can result in leakage of very hot exhaust gases, around 4500°R, into the actuator compartments. Nozzle structure and cooling become critically important at these high speed conditions. Nozzle size and weight problems are magnified with variable geometry and added cooling that must be taken into account. Preliminary nozzle designs indicate that weight and size may be as much as four times that of a conventional nozzle for a Mach 1.5 aircraft.

RAMJET COMBUSTOR (RAMBURNER)

The ramburner must withstand the thermal environment and structural loads from Mach 1.5 to 6.0. If the mission application happens to involve a man-rated system, the structural duty cycle can extend to many cycles for extended periods of time. As a structural goal, a duration of two hours per flight for 250 flights seems reasonable. To minimize the size of the ramburner cross-section stoichiometric fuel/air operation could be required with associated gas temperatures around 4500°R. Ramburner walls are likely to be cooled with air or direct fuel cooling in a regenerative structure. Flameholders and fuel injectors will likely be fixed instream devices with associated thermal cooling problems. Low air temperature (e.g. low speed) ramburner operation may require a pilot excessively large flameholder for flame stabilization. These are contrary to the requirements at high temperature where fuel/air autoignition will be achieved easily. Prior

combustion data suggest that the mixing limited condition exists at high temperature and more instream fuel injectors may be needed to achieve high efficiency. Liquid and gaseous fuel injection will be required and will add further complication to the injector design.

COMPONENT INTEGRATION

Component integration will be the ultimate challenge in demonstrating a complete propulsion system that has good overall performance and minimum weight. Mode transition control must be accomplished smoothly without causing disruption of any component. For example, the gas turbine compressor should have wide stall margin limits and stable windmilling characteristics for smooth shutdown and restart. For sustained speeds above Mach 4, it will become necessary to thermally isolate the gas turbine since the air temperature will be too high for the structural materials and bearing lubrication system. Engine thermal control must consider cooling air flow path and flow rate requirements to maintain structural integrity. Air flow management for the engine internally will require variable geometry in the form of compressor inlet guide vanes or some air valve in the inlet subsonic diffuser to seal and direct the air flow to the appropriate operating mode. Engine controls will necessarily be more complex than usual to maintain optimum settings for the inlet, nozzle and internal engine components.

OTHER CONTRIBUTING PROGRAMS INCLUDE

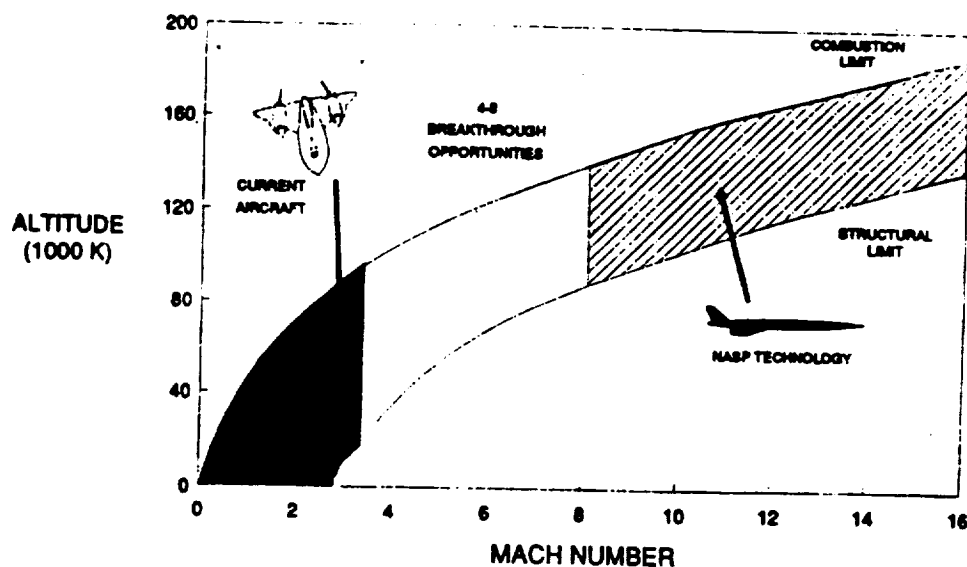
The heat pipe radiation cooling for high-speed aircraft propulsion program, the ceramic regenerator program, the endothermic fuel/catalyst development and evaluation program, the endothermic fuels program, the inlet and nozzle concepts for advanced airbreathing propulsion program, fundamental ramburner combustion studies, high speed turboramjet combustor development program, and the high mach turbine engine technology program.

The High Mach Turbine Engine Technology to be demonstrated over this next decade will open up a new era in mission applications and tactics by doubling the speed range capability of current systems. High speed intercept and early warning equates to effective deterrence; a cornerstone in our strategic defense philosophy. Timely reconnaissance and surveillance improves response flexibility and decision time so that measured responses can be made without overreacting to situations. In fluid situations where targets and scenarios are constantly changing, rapid strike capability keeps time urgent targets at risk. A simple force projection to show national interest/resolve might prevent potential adversaries from taking steps to increase hostilities. High speed can also improve system survivability and provides a hedge against anti-stealth technology breakthroughs.

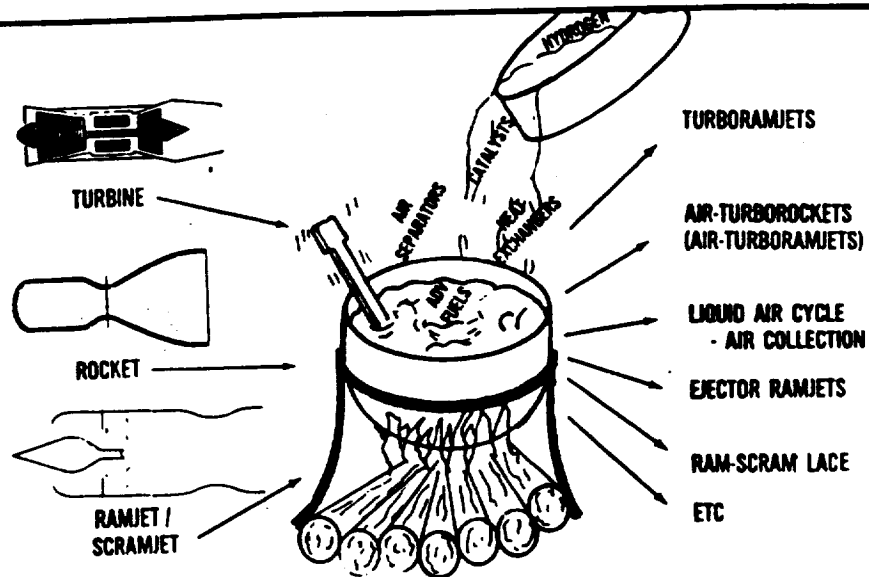
Commercial applications for this engine technology include high speed passenger/transport aircraft and accelerator stages for horizontal takeoff, earth-to-orbit launch vehicles. As the Pacific Basin area evolves as a strong economic area, timely access to this region from the United States and Europe for both passengers and materials will be important economically. Interest in low-cost access to space and the ever increasing backlog of payloads has fueled national interest in alternate methods to achieve launch capabilities. Reusable launch vehicles have been studied by a number of countries. The turboramjet using hydrogen fuel has in many cases shown to be the preferred low speed propulsion system for these vehicles.

This technology will allow the United States commercial aviation industry to maintain a clear leadership in response to foreign pressures from Germany, France, Japan, and the Soviet Union, and to continue to be a strong source for domestic and international aircraft.

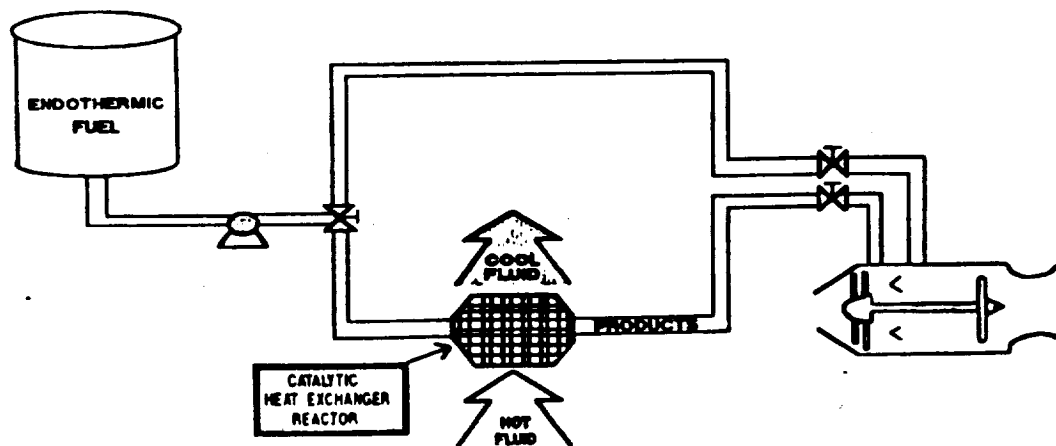
HYPERSONIC BREAKTHROUGH OPPORTUNITIES



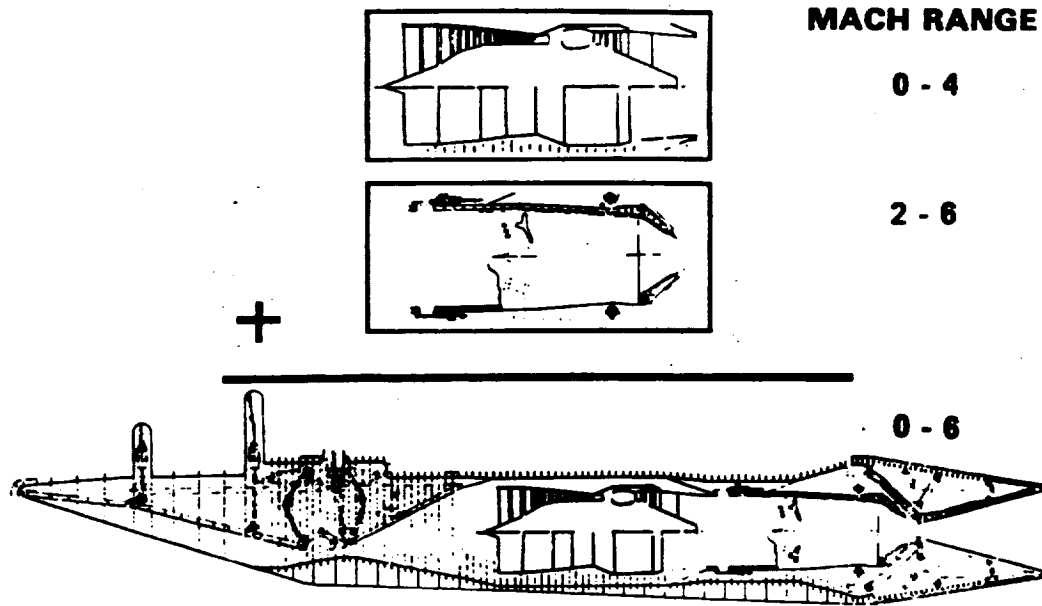
COMBINED CYCLE ENGINES



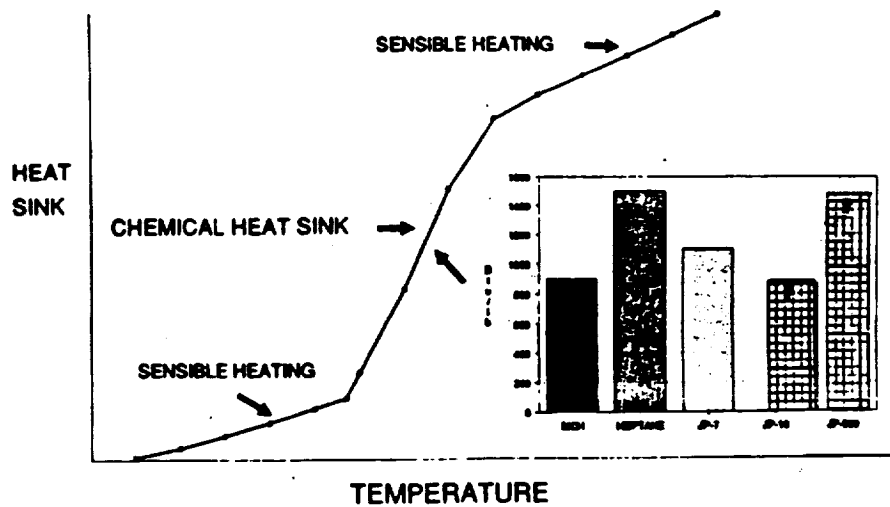
ENDOTHERMIC FUEL SYSTEM



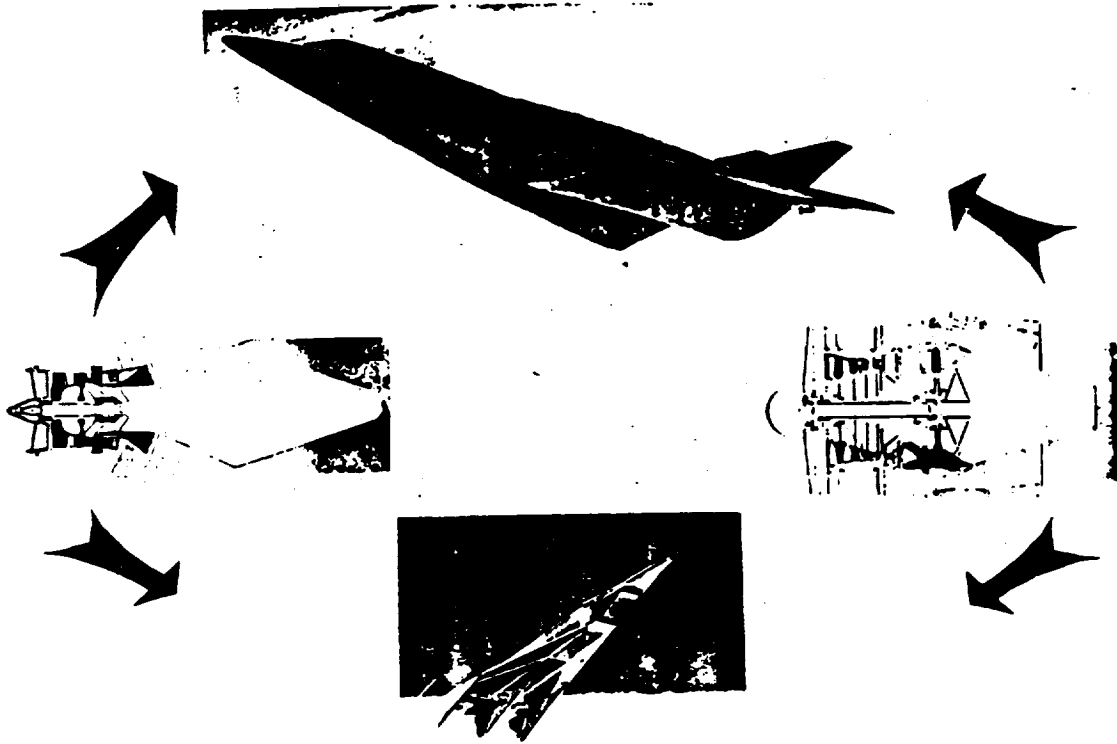
THE SOLUTION TO THE 4 - 6 TECHNOLOGY GAP



ENDOTHERMIC FUELS



COMBINED CYCLE ENGINE APPLICATIONS



NASA/AF HIGH MACH TURBINE ENGINE

- OBJECTIVE: TO CONDUCT DESIGN STUDIES AND CRITICAL COMPONENT EXPERIMENTS OF ADVANCED TURBINE ENGINE SYSTEMS WHICH OPERATE IN THE MACH 4-6 REGIME

- STATUS: TWO (2) CONTRACT AWARDS

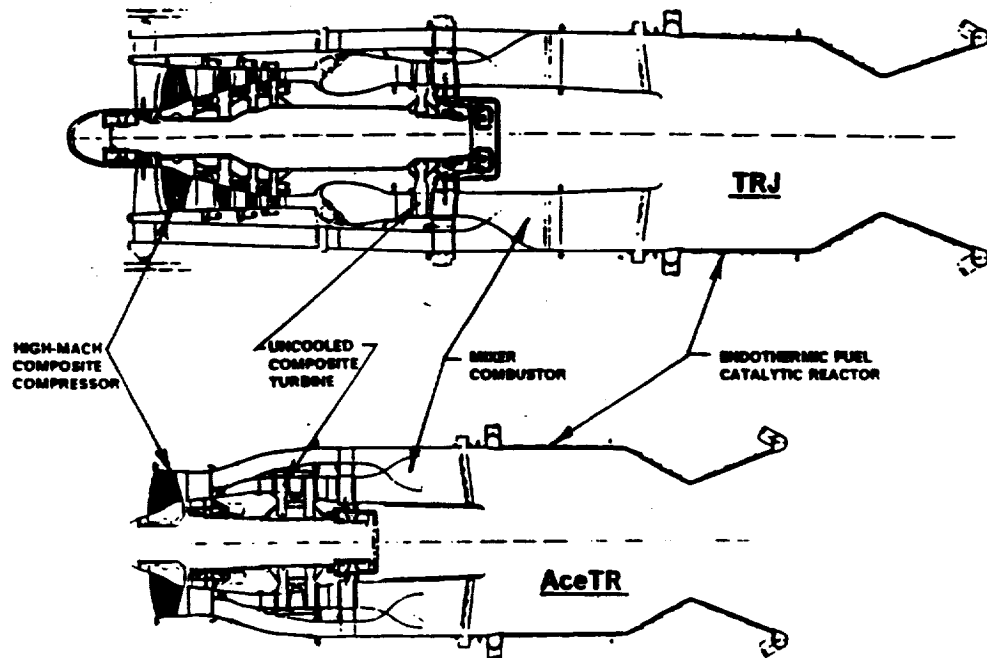
NA3-26051 - GENERAL ELECTRIC
NA3-26052 - PRATT & WHITNEY

TECHNICAL WORK BEGINS IN EARLY JUN 90
FIVE (5) YEAR TECHNICAL EFFORTS THRU JUN 95
113,000 MANHOURS OF EFFORT EACH

ORIGINAL PAGE IS
OF POOR QUALITY

CRITICAL ENGINE COMPONENT TECHNOLOGIES

Needed For Both TRJ and ATR Applications



COMBINED CYCLE ENGINES RECENT ACCOMPLISHMENTS

DESIGN STUDIES

- DESIGN STUDIES COMPLETED ON MACH 5.5 TTFRJ & MACH 5.0 AceTR
- CRITICAL COMPONENTS IDENTIFIED
- NASA LANGLEY FUNDED MACH 5 WAVE RIDER USING OVER/UNDER TRJ

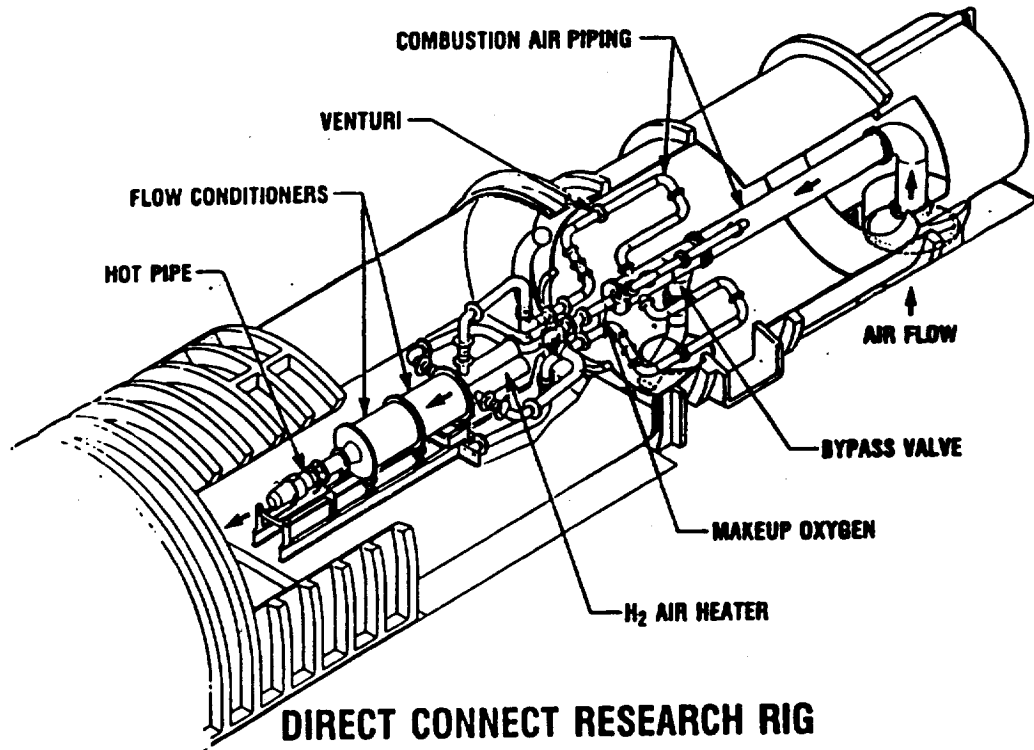
TURBORAMJET

- INITIATED MAN RATED HEAT EXCHANGER REACTOR
- INITIATED RAMBURNER FOR DEMONSTRATION IN WL TEST CELL 22

AIR TURBOROCKET

- INNOVATIVE COMPRESSION CONCEPT PERFORMANCE DEMONSTRATED WITH SIMULATED NORPAR 12 FUEL PRODUCTS
- INITIATED DEVELOPMENT OF FUEL COOLED STRUCTURE HEAT EXCHANGER/REACTOR

PSL-4 HYPERSONIC MODIFICATION



SUPERSONIC FREEJET INSTALLATION

